Chapter 4: Monitoring the Debris Environment

I. Current Activities and Research

A. Space Surveillance Catalog

The SSN maintains a catalog of man-made objects in space. To accomplish this task, a worldwide array of sensors has been established. The observations from these sensors are compiled into a single database and its associated document, the Space Surveillance Catalog. There are approximately 7000 on-orbit objects large enough to be cataloged. Only objects which can be consistently tracked and whose source can be identified enter the catalog. It should be emphasized that the SSN was never intended to track the small debris. Debris assessment is secondary to its primary missions. The SSN sensors provide positional data on the objects and a rough approximation of size in terms of radar cross section. Using data from these and other sources, various characteristics about the debris are studied, including radar and optical reflectivity, shape, mass, and orbital characteristics and decay.

Figures 16 and 17 show the location of the SSN sensors. These sensors can be divided into two categories: (1) radars, and (2) optical. Radars are typically used for LEO observations since they provide continuous coverage, independent of weather and twilight conditions. Typically, optical sensors are used for deep space observations since the sensor's sensitivity falls off less rapidly with range. Because of the variation in physical properties of debris, causing some objects to be more difficult to detect by one sensor or the other, the optical and radar measurements are complementary.

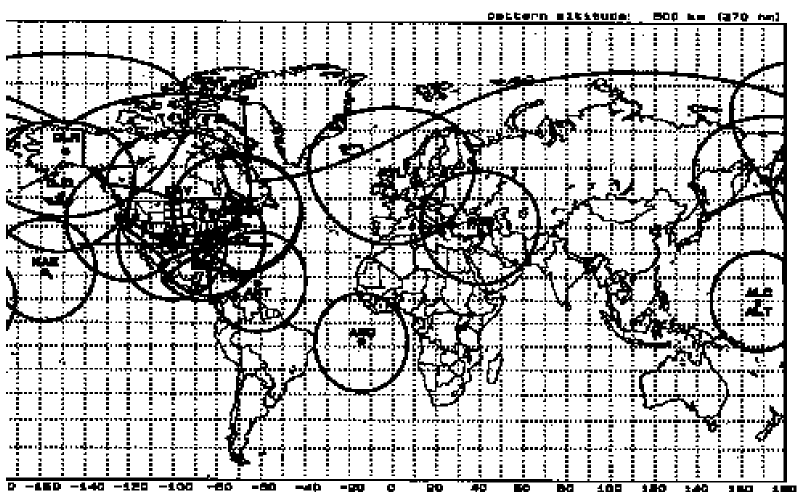

Figure 16. Space Surveillance Network Radar Sensors and Field of View at 500 km Altitude

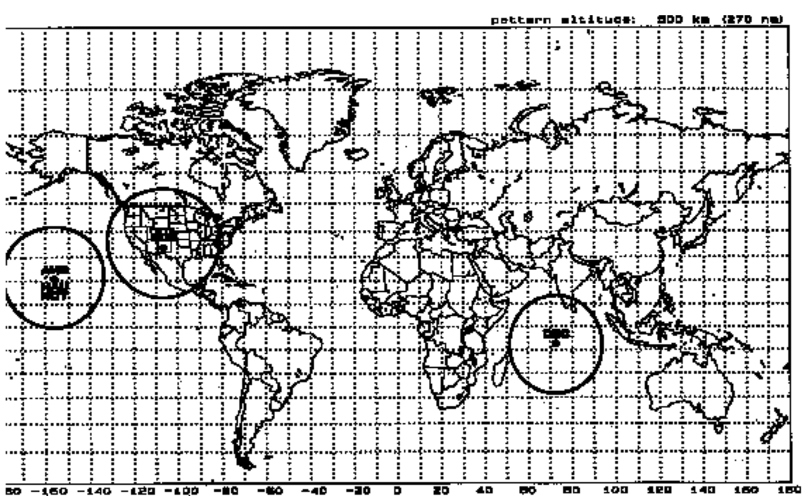

Figure 17. Space Surveillance Network Optical Sensors and Field of View at 500 km Altitude

B. Radar Measurements

One significant source of new data on small debris has come from operation of the Haystack Radar. This radar has been operated in a staring mode for a sufficient number of hours to get statistical data on the population of debris 1 cm and larger at 500 km altitude. In this mode, the radar is positioned near the zenith, and debris objects are detected as they cross the 0.05 degree beam of the radar. Several thousand hours of operation have been completed, and a substantial database has been accumulated. Figure 18 shows a plot of data from this radar, compared with computer model predictions.

The Goldstone Deep Space Network radars have also been operated to obtain statistical data on small debris. This radar is capable of detecting 2 mm objects at 1000 km altitude. Observation time on this radar is very limited because of commitments to the primary mission of these radars, which is to monitor deep space probes.

C. Optical Measurements

Optical sensors provide another technique to measure and study space debris. Several ongoing programs are collecting optical data from various sites around the world.

DOD has sponsored an optical measurements program using facilities located at the Phillips Laboratory Air Force Maui Optical Station (PL/AMOS) and the MIT/LL ETS in Socorro, New Mexico. In this program, the focus has been on estimating the debris population and the development of observational techniques to allow orbital determination of uncataloged debris [ref MIT/LL and PL/AMOS SSW papers 93,94]. These observations have provided the first direct measurements of the orbital elements of small uncataloged debris and exposed significant differences between the orbital distribution of the total space population and the catalog. Hundreds of hours of data have been collected and analyzed to derive a population estimate. Results indicated that there are approximately 20,000 objects larger than 5 cm; this result is consistent with the Haystack results in the same size regime.

There is some evidence that debris may be accumulating in GEO. For that reason, the NASA CCD debris telescope has been used in a search for debris near GEO altitudes. Some small, fast-moving objects with the orbital characteristics expected of debris from breakups have been found. Similar searches are being conducted by the AFSPC at the Maui GEODSS site. NASA is also sponsoring measurements with the Diego Garcia GEODSS site searching for breakups in GTO.

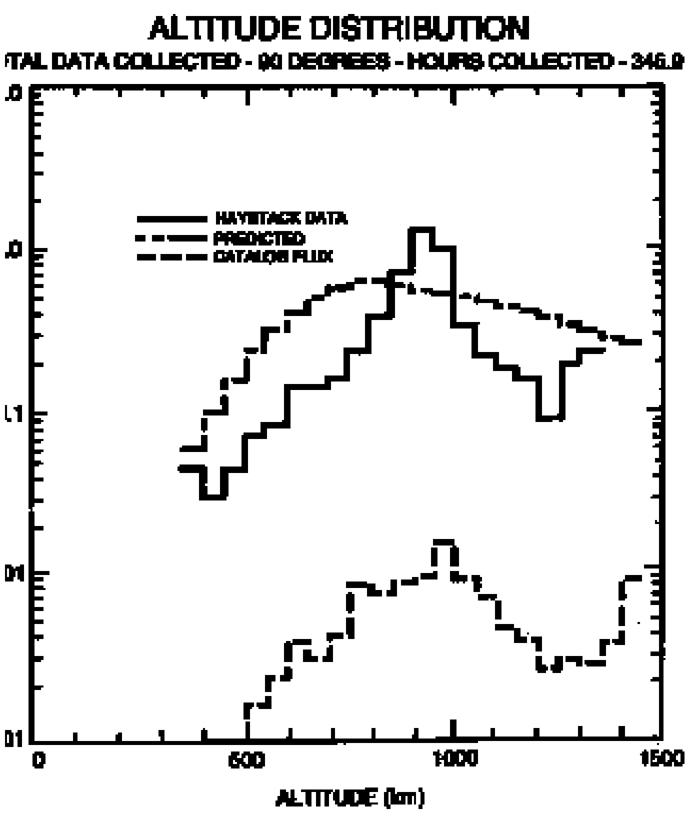

Figure 18. Haystack Small Object Observations. The bottom line is the catalog population. The dashed line is the expected observations and the solid line the actual observations.

II. Opportunities for Improvement and Future Research

A. Evaluate and Exploit Existing Capabilities

The SSN maintains the capability to measure smaller sizes than are currently cataloged. This capability was tested for LEO during June 1993, using the phased array radars at their maximum sensitivity and using the optical sensors usually used for GEO observations. The test showed that the SSN sensors can be used to provide statistical data for debris at sizes below 10 cm in LEO.

It was found that many of the small debris fragments were in elliptical orbits, suggesting that elliptical orbits are more abundant than represented by the catalog. These results are consistent with the conclusions from impacts found on LDEF, statistical measurements by the Haystack radar, and orbital distributions determined by MIT/LL.

It should be emphasized that the SSN was never intended to track small debris objects. The Firepond optical tracking facility at MIT/LL has been coupled to the Millstone and Haystack radars to make simultaneous measurements of radar cross section and optical magnitude.

B. Expansion of Existing Capabilities–Radars

The Have Stare radar, located at Vandenberg Air Force Base in California, is an X-band 200 kw tracking radar that will come on line during 1995. It can detect small debris in the 1 to 10 cm range, depending on altitude. It may eventually be moved to another site, as yet undetermined.

NASA and the DOD have jointly developed the Haystack auxiliary radar. This K-band radar will have a capability similar to Haystack, but will not be quite as sensitive.

C. Expansion of Existing Capabilities–Optical Sensors

Existing ground-based optical systems are intended for tracking satellites above 5000 km altitude. However, they are inherently capable of detecting orbital debris at lower altitudes, with a limit of about 5 cm at 500 km altitude. The use of these sensors to provide statistical debris flux data at altitudes below 5000 km can be explored. Incorporating new CCD technology into existing optical systems could improve the detection and tracking capability for GEO.

D. New Facilities–Optical

A 3-meter aperture liquid mirror debris telescope is under construction by NASA. This instrument will be capable of detecting 2 cm debris in LEO and 10 cm debris in GEO. Since the telescope is zenith-pointing and cannot track objects, only statistical measurements of orbital debris are possible. The instrument must be located near the equator to permit observations of GEO.

The DOD is investigating using the 3.5 meter Advanced Electro-Optical System telescope being built at the PL/AMOS facility for debris measurements.

E. Space-Based Measurements

The Midcourse Space Experiment is a satellite planned for launch by the Ballistic Missile Defense Organization. The optical sensors aboard this satellite have the capability for orbital debris measurement, and several experiments are planned. The optical sensors include the ultraviolet, visible, thermal infrared spectral ranges. Particulate matter spawned by the spacecraft will be monitored by on-board light scattering experiment.

The Clementine mission included a microparticle detector mounted on the adapter between the rocket engine and the payload. This adapter remained in a highly elliptical Earth orbit after the Clementine spacecraft left Earth orbit. The microparticle detector monitored particles in the 1 to 10 micron range.

F. Returned Material Analysis

Impact pits on material that has been exposed to the space environment provide information about the microdebris environment. Chemical analysis of residue in the impact pits is used to discriminate between micrometeoroids and orbital debris. The LDEF was in orbit for 69 months, and has provided a wealth of data that is still being analyzed. Examples of other such material include the Hubble Space Telescope solar panel, witness plates exposed in the Shuttle Orbiter payload bay, and the EURECA. As part of the series of joint Shuttle-Mir manned flights, an experiment is planned that will place on the outside of Mir a sophisticated capture surface that will preserve the chemistry of the impacting particles.

G. Laboratory Studies of Breakups and Collisions

Input data are needed for modeling the effects of hypervelocity collisions and propellant explosions. Laboratory tests have been conducted by DOD and by ESA to simulate the effects of collisions and explosions, respectively.

Because impacts in low Earth orbit occur with an average speed of 10 km/sec, specialized equipment is needed to create and monitor realistic impact events. Current and future studies include: (1) gun research and development, (2) hypervelocity impact research testing to determine the effect of collisions on materials and spacecraft structures, (3) hypervelocity impact modeling, and (4) spacecraft subsystem and component impact testing and analysis.

Shown here is a 3-meter-diameter telescope mirror formed by a rotating pool of liquid mercury. The scientists are wearing masks to guard against toxic mercury vapor. The optical quality of the mirror is excellent, and the cost is a factor of ten or more less than an equivalent glass mirror. NASA is using this mirror as part of a low-cost, large-aperture telescope to monitor the part of the debris population not observed by radar. This telescope can detect orbiting debris objects as small as 2.5 cm at 1000-km altitude. It is currently located in the mountains of New Mexico, near the town of Cloudcroft.